Stabilized Gimbal for Airborne Water Surface Velocity Measurements in Riverine and Littoral Environments

Final Report for FY13 DURIP (ONR Code 322CG)

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Summary
Over the past several years, the COHSTREX (Coherent Structures in Rivers and Estuaries Experiment) and DARLA (Data Assimilation and Remote Sensing for Littoral Applications) projects have provided new insight into the nature of flows in rivers, estuaries, and tidal inlets. An especially successful aspect of COHSTREX has been the application of infrared imagery to detect coherent structures in rivers and to quantify their turbulence characteristics. Particle Image Velocimetry (PIV) techniques were successfully applied to the infrared measurements, which included both tower-based and airborne deployments. The airborne measurements were made with a lighter-than-air infrared imaging system based on a Helikite, which is a tethered helium-filled kite. The tower-based cameras provided images of O(10 m) size and resolution of O(1 cm) and the Helikite provided images of O(100 m) size and resolution of O(10 cm). The PIV techniques applied to IR imagery from both platforms provided mean and turbulent velocities. The development of stabilized gimbals with improved pointing specifications and raw digital output provide the opportunity to transition these techniques to light aircraft.

Through this DURIP we acquired a stabilized gimbal system with both an electro-optical (EO) camera and a remote-focus, cooled, mid-wave infrared (IR) camera. The system provides the capability to simultaneously measure mean surface velocities over an area of O(100 m) in horizontal field-of-view and turbulent velocity characteristics with spatial resolution of O(0.10 m). Riverine applications include mapping of mean velocities and derivation of surface Reynolds stresses that have been shown to correlate with bottom roughness. Littoral applications include investigation of tidal inlet flow, coastal river plumes, internal waves and nearshore circulation. This new airborne capability will allow us to apply these techniques to survey the spatial variability of mean and turbulent water-surface velocities over large areas with high resolution. The system is deployed on a light aircraft (Cessna 172) with onboard control and data recording on a custom computer system.

The use of this IR/EO gimbal will include:

- Application of PIV techniques to IR imagery of water surfaces
  - Capability to simultaneously measure mean and turbulent surface velocity from an aircraft using infrared imagery
  - Investigate the correlation of surface Reynolds stresses with river bottom roughness
- Investigate tidal inlet flow, coastal river plumes, and nearshore circulation

- Mapping coastal surface temperature features due to internal wave activity and kilometer-scale circulation

Outcome

Through the Applied Physics Laboratory and University of Washington purchasing procedure, a competitive bidding process was undertaken to choose a gimbal manufacturer, as no existing gimbal met the specification required. The chosen engineering firm, Trillium Engineering in Hood River Oregon, manufactured a custom version of their Orion HD80 model gimbal that contains a cooled midwave IR camera (FLIR Neutrino), COTS visible camera and onboard INS/GPS stabilization. The most significant feature is the ability of this gimbal to transmit raw IR and visible imagery for recording. A custom sampling system was developed at APL to control the gimbal and cameras and record the data. Gimbal technical drawings are shown in Figure 1, and Table 1 lists the gimbal capabilities.

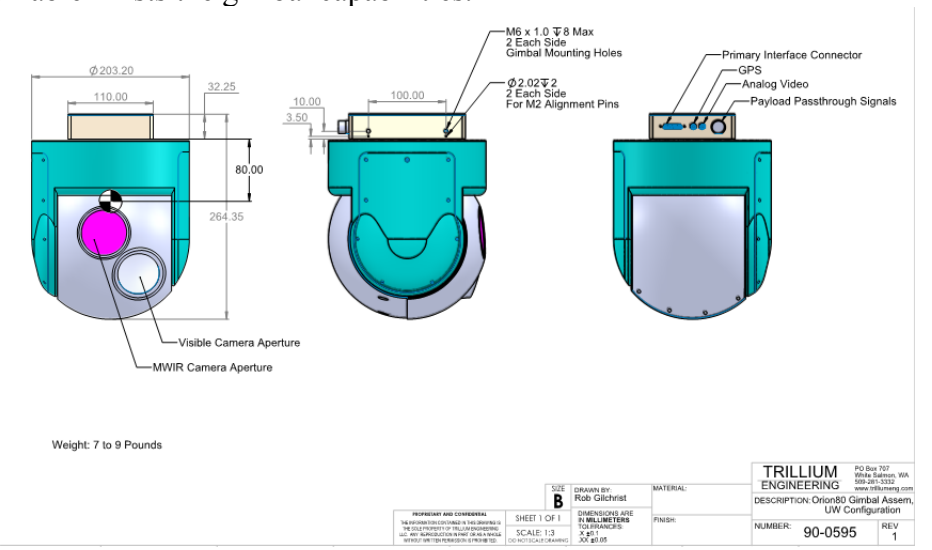

Figure 1. Technical gimbal drawings (by Trillium Engineering) showing the main components, camera ports and windows, connectors and overall dimensions (in mm).

Table 1. Gimbal Attributes

weight, size	< 9kg, 9" ball, 10.4" maximum dimension
voltage, power	9-30V, < 50W
pointing modes	fixed, stabilized, staring (geo-pointing)
stabilization jitter	200 µrad, (0.01°)
position and attitude output	>10Hz rate, resolution < 100 µrad, (< 0.006°)
MWIR camera	FLIR Neutrino 640x480 array, NETD < 25 mK 35° FOV, remote focus GigE data output
visible camera	Point Grey Flea 3 2MP resolution, 35° FOV GigE data output
temperature measurements	(3) IR lens, body, and window - Dallas DS1820

The gimbal was mounted and tested on a Cessna 172 (owned and operated by Regal Air) over the Snohomish River on 14 October 2014. Figure 2 shows the gimbal attached on the custom mount on the underside of the Cessna. The gimbal is mounted in a *roll-over-tilt* orientation so that it will avoid gimbal-lock in a typical downward pointing orientation. The gimbal performed as expected with excellent stabilization in the turbulent conditions on the test day, and it demonstrated very good geo-pointing capability (continued staring at a fixed ground location while transiting). Figure 3 shows simultaneous snapshots from the thermal and visual cameras.

Figure 2. (*left*) The gimbal as is mounted on the belly platform of the Cessna 172 survey plane. (*right*) A close-up of the gimbal showing the windows for the visual (EO) and the mid-wave thermal (IR) cameras. Cabling into the cabin for the data output, serial control and power are not visible in the picture.

Figure 3. (*left*) Visual band image, and (*right*) thermal IR band image from a bend in the Snohomish River near Everett WA. Cooler brightness temperatures, including the relatively cold river, are displayed as low (dark) intensities.

Future Navy Research Application

This new gimbal will be used in an ONR funded DRI on inner shelf dynamics (Inner Shelf DRI), with a pilot experiment to take place in the summer of 2015 off the southern California coast. The MWIR gimbal data will be collected simultaneously with SAR data to map the surface temperature and currents associated with flow structures, internal waves, and mixing near the coastline.

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A stabilized gimbal system, comprised of both an electro-optical camera and a focusable cooled mid-wave infrared camera was acquired, and a frame was built to deploy the gimbal on a light aircraft in conjunction with the current DoD/ONR-funded project designated DARLA (Data Assimilation and Remote Sensing for Littoral Applications). This created new airborne capabilities to exploit remotely-sensed thermal signatures for littoral application. Specifically,it will be used with existing techniques to survey the spatial variability of mean and turbulent water surface velocities over large areas with high resolution.

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